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HYDROGEN AS A FUEL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A short summary is given of continuing efforts directed toward evaluating the performance and problems of hydrogen-fueled piston engines and gas turbines and toward investigating the potential and problems of hydride and cryogenic storage of hydrogen.		

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INTRODUCTION*

During the past semi-annual report period, two areas received major technical concentration: hydrogen utilization and hydrogen storage. At a relatively low level, hydrogen use in reciprocating engines was investigated beyond the results detailed in the preceding semi-annual technical report (Ref. 1). Additionally and at a higher effort level, the use of hydrogen as a gas-turbine fuel was investigated. In the area of hydrogen storage, both hydride and cryogenic modes of storage received attention. In all of these areas, investigation was by means of literature review, consultation with various experienced hydrogen users, and analysis; no experiments were conducted since none were indicated as both necessary and consistent with the scope of the subject effort.

RESULTS

The technical efforts and results obtained can be summarized as follows:

Reciprocating Engines

- (1) Carburetted, spark-ignition engine performance with hydrogen is largely as might be expected. Hydrogen fuel/air-cycle calculations have been carried out (see, for example Fig. 1). Hydrogen engine-cycle calculations, previously lacking, largely support experimental observations. Under comparable conditions, efficiencies with hydrogen and hydrocarbon fuels are very similar. Hydrogen suffers, however, 20-25% peak power output penalty.

* In light of the short term remaining for the present contract, an abbreviated technical report is provided at this time in the form of a Technical Report Summary only. The abbreviated form was agreed to by cognizant personnel at the Office of Naval Research and the Naval Ship Research and Development Center.

- (2) Calculations and interpretation of existing data (Fig's. 2&3) show that hydrogen injection into a closed, reciprocating-engine cylinder, while unproven practically, promises to eliminate hydrogen's 20-25% power penalty with a negligible change in efficiency, if injection is at low pressure.
- (3) High-pressure injection during combustion (following spark ignition) remains to be demonstrated despite some promise for moderating hydrogen's tendency toward high rates-of-pressure rise during combustion (e.g., 30 atm/msec.)
- (4) Compression-ignition hydrogen engines are probably not practical judging from conflicting data from the literature and from personal communications.

Gas Turbines

- (5) Conventional gas turbines fueled with hydrogen were calculated to show modest power-output increases (e.g. 5%) with slight efficiency decreases (e.g., 1-2%) (Table 1, Fig. 4). Literature data and personal communications as well as cycle calculation (e.g., Fig. 5) suggest that little gain in NO_x emissions may be achievable with hydrogen relative to advancing hydrocarbon combustor designs.
- (6) Preliminary calculations show that substantial practical performance gains (e.g., 20%) for hydrogen-fueled gas turbines are likely only with use of cryogenic fuel as a heat sink for turbine cooling air (Table 1).
- (7) Unresolved problems with reliable, efficient cryo-pumping of hydrogen and with demand-matching of liquid hydrogen vaporizers and pumps have been identified by careful review of earlier data and heat-balance calculations.

- (8) No long-term reliability data (e.g., 1000 to 10,000 hrs) have been found in the literature for any type of hydrogen engine.

Storage

- (9) According to one current effort elsewhere, methylcyclohexane (proposed as a hydrogen storage medium) affords little advantage in volumetric energy density (cp., cryogenic hydrogen) and incurs substantial problems with practical use of waste heat recovery to release hydrogen.
- (10) Unresolved metal-hydride problems reported in the literature and via personal communications include transient response (hydrogen release rates), poisoning by contaminants, and diminution with cycling as well as the low mass of hydrogen stored per unit weight of hydride.
- (11) Data on energy loss (Fig.5) boil-off and (Fig.7) chill-down losses and on weights of cryogenic hydrogen storage vessels (Fig.8) have been assembled. Such data are of limited availability but indicate rough trends regarding performance of storage systems which have been demonstrated in practice.

FURTHER WORK

Further investigation is indicated and planned in the areas of cryogenic fuel handling (pumping, heat exchange), gas-turbine performance gains and problems with cryogenically-cooled turbine-cooling air, novel hydrogen combustors (premixed catalytic, photochemical), and state-of-the-art and problems encountered in metal-hydride bed design. More detailed and comprehensive treatment of the subjects of the present semi-annual report as well as of additional areas is planned for the Final Technical Report under the subject contract.

REFERENCES

1. McAlevy, R.F., III et al, "Hydrogen As A Fuel", Semi-Annual Technical Report under Contract N00014-67-A-202-0046, Aug. 31, 1974 (AD 787-484)

CONFIGURATION	FUEL	OPERATING CONDITIONS	OPTIMISTIC & INCREMENTS (ESTIMATED)			
			EFFICIENCY & FUEL CONSUMP.	POWER	ENGINE WT.	ENGINE VOL.
Baseline	HC	Full power, simple cycle OPR=20/1 TIT=3000°R	-	-	-	-
Reference	H ₂	"	-1 to 2%	+5 to 15% (1)	+10% (2)	+5% (2)
Ref. + Oil Cooling	"	"	-	-	+20%	6%
Ref. + Turbine Blade Cooling	"	"	+5% (Prelim.)	+10-25% (Prelim.)	20%	6%

NOTES

(1) TVR decrease from 1.2 to 1.1; 2-3% increase in specific work

(2) Assuming cryogenic fuel system, excluding storage tank

TABLE 1
ESTIMATED PERFORMANCE INCREMENTS
WITH HYDROGEN GAS-TURBINE FUEL

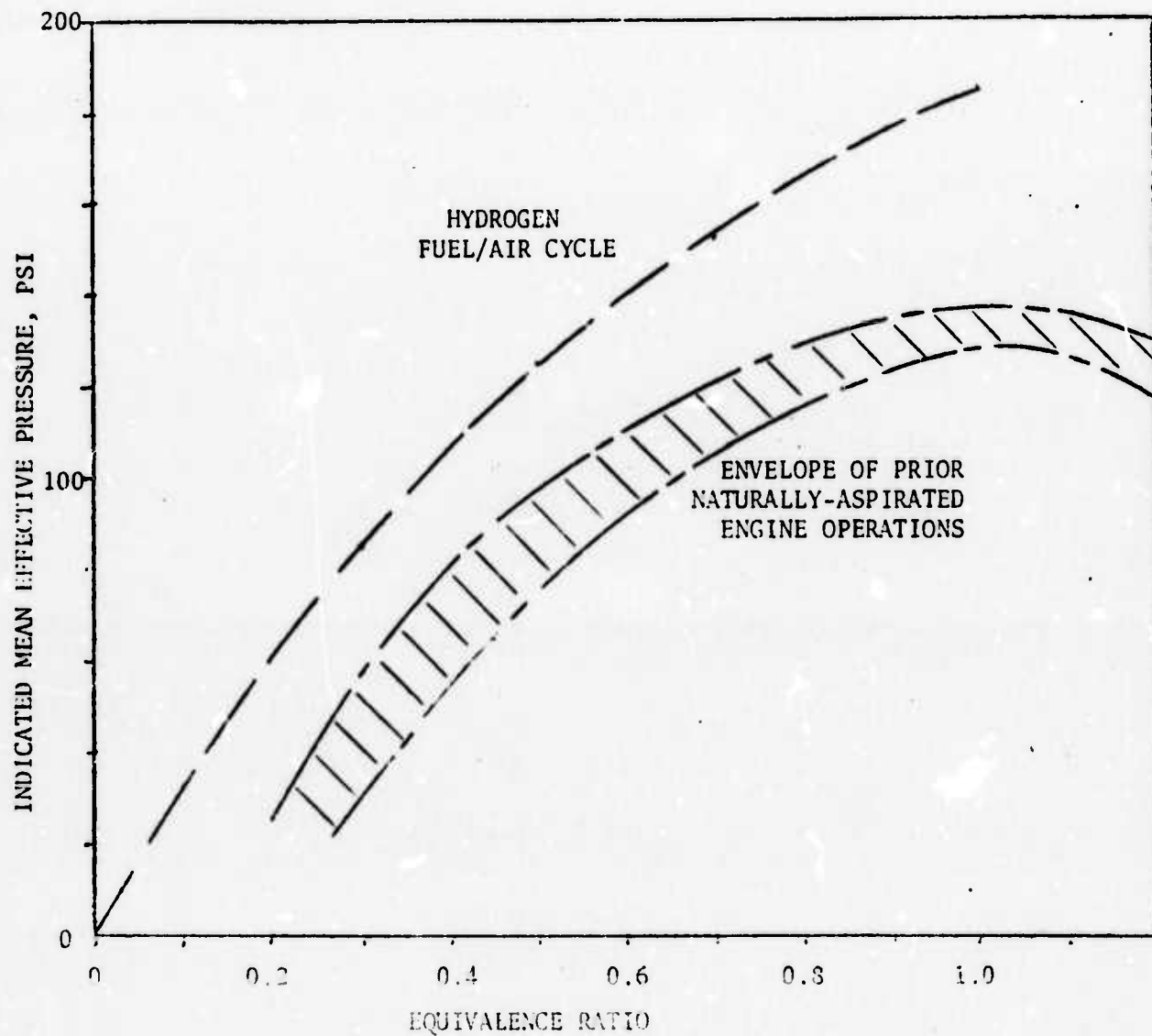


FIGURE 1
REPRESENTATIVE RESULTS OF FUEL-AIR CYCLE
FOR HYDROGEN-FUELLED OTTO-CYCLE AT
COMPRESSION RATIO = 10/1

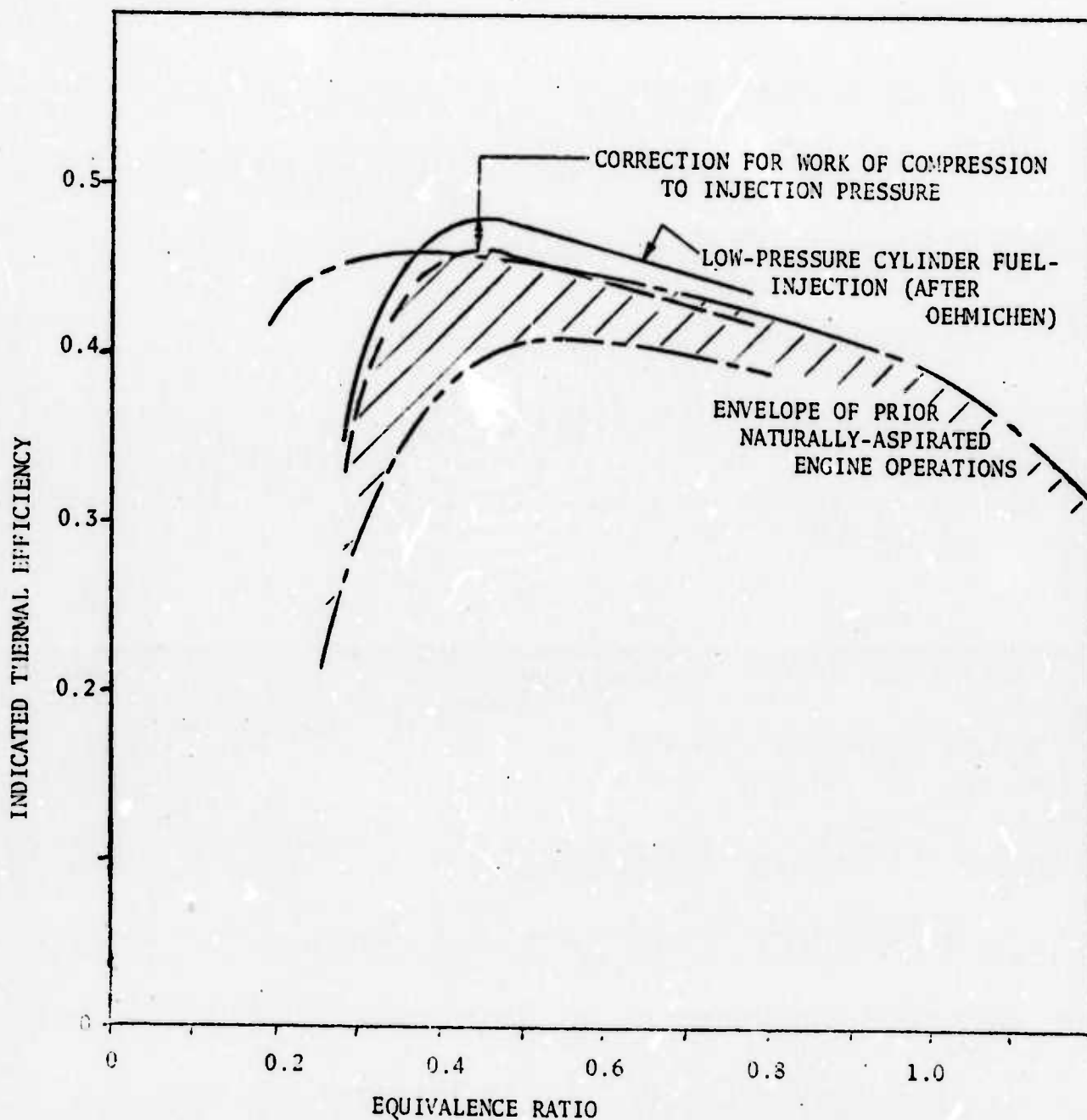


FIGURE 2

REPRESENTATIVE THERMAL EFFICIENCY COMPARISON OF
NATURALLY-ASPIRATED & CYLINDER FUEL-INJECTED
OTTO-CYCLE ENGINE OPERATIONS
(COMPRESSION RATIO = 10/1)

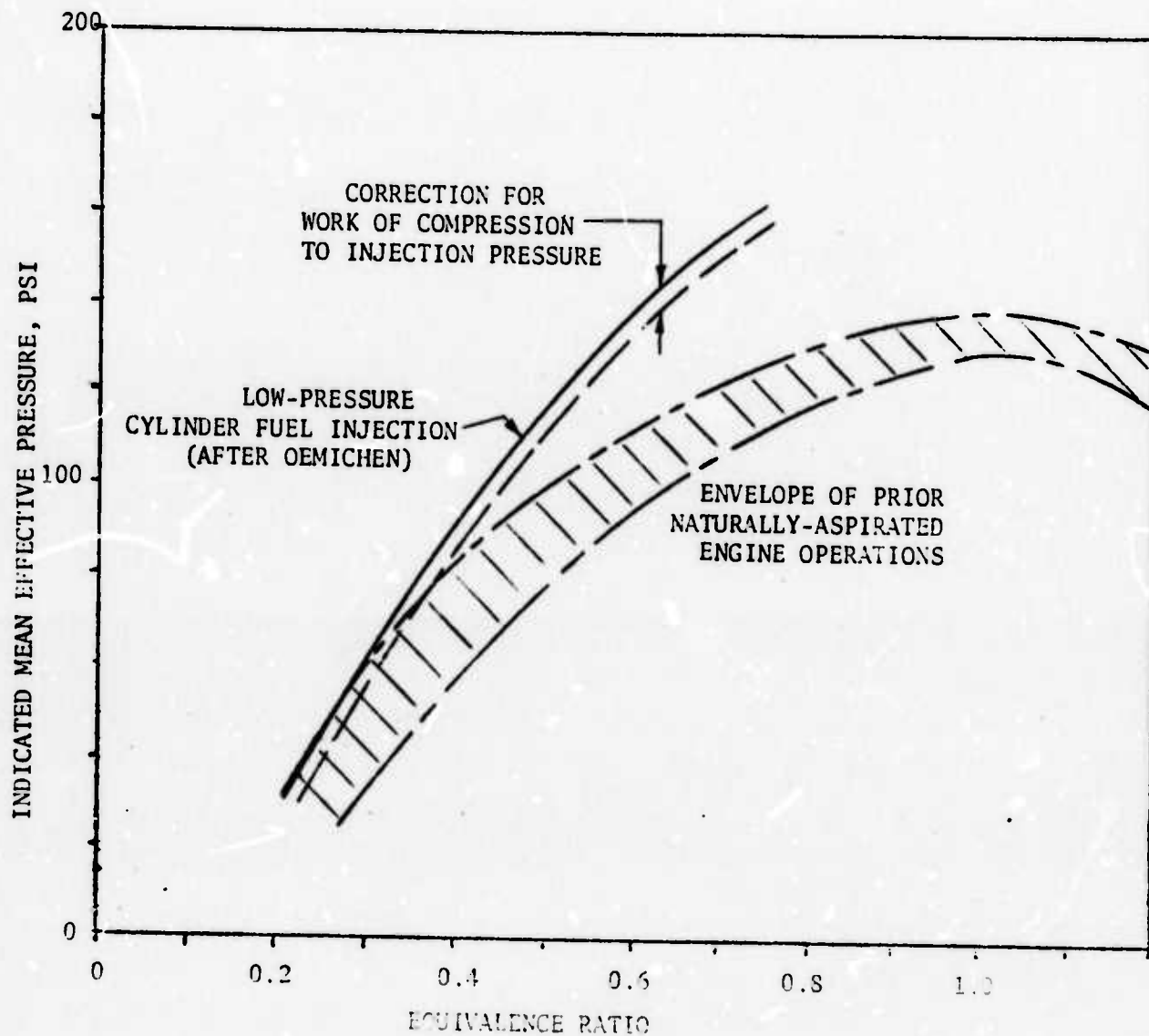


FIGURE 3
REPRESENTATIVE MEAN-EFFECTIVE PRESSURE COMPARISON OF
NATURALLY-ASPIRATED & CYLINDER FUEL-INJECTED
OTTO-CYCLE ENGINE OPERATIONS
(COMPRESSION RATIO = 10/1)

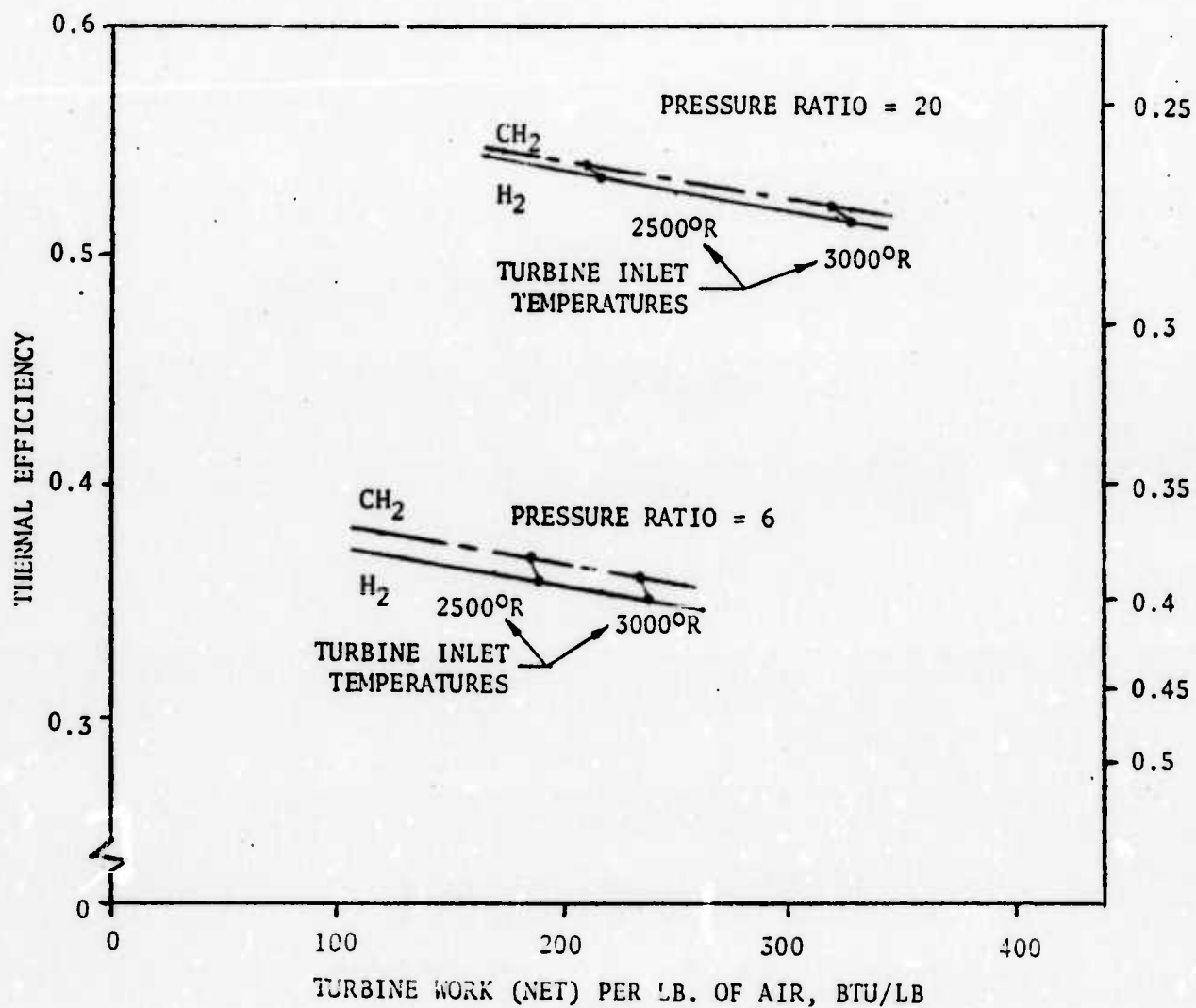


FIGURE 4
COMPARISON OF SELECTED-HYDROCARBON AND
HYDROGEN GAS-TURBINE CYCLES
(IDEAL BRAYTON CYCLE)

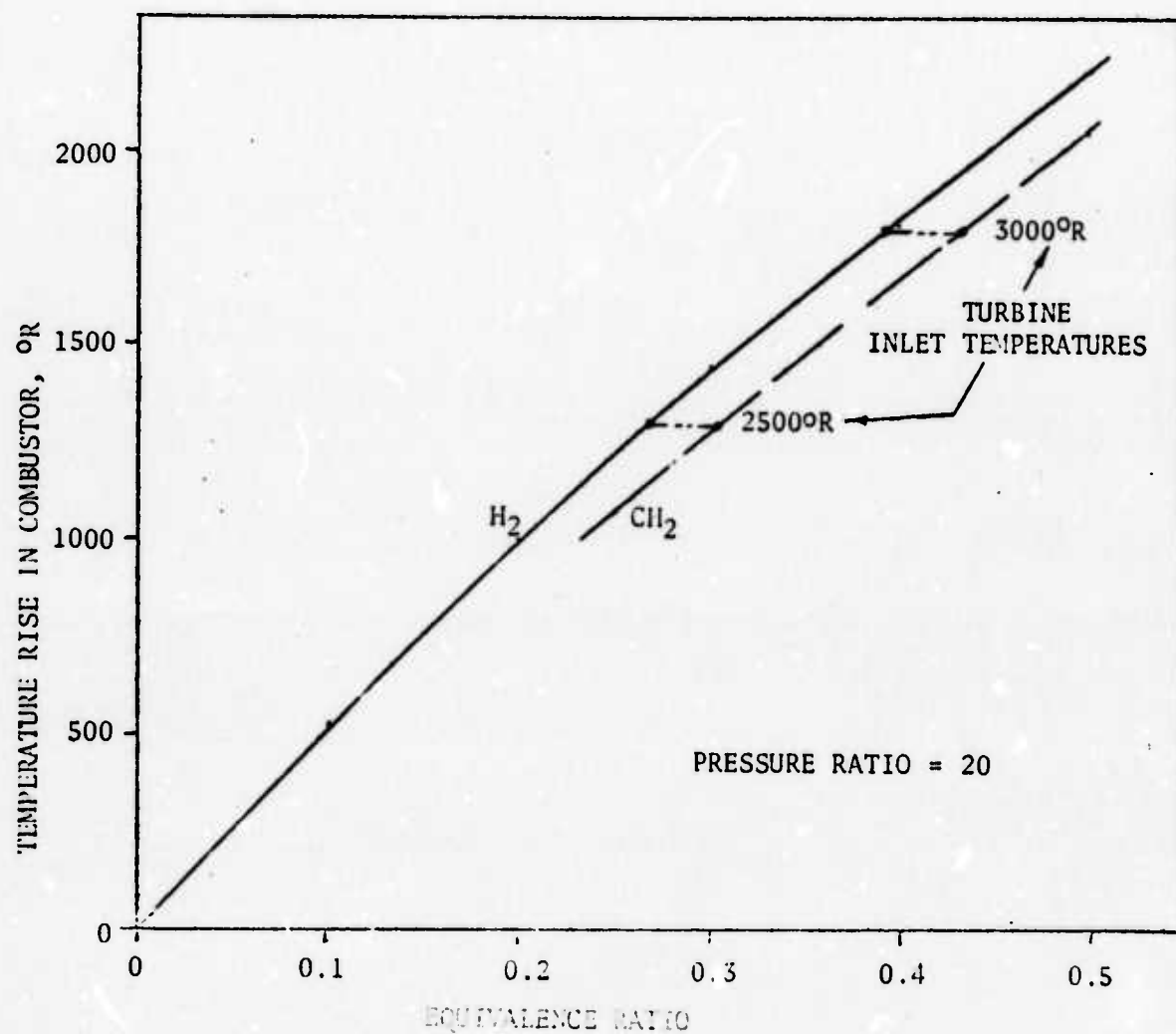
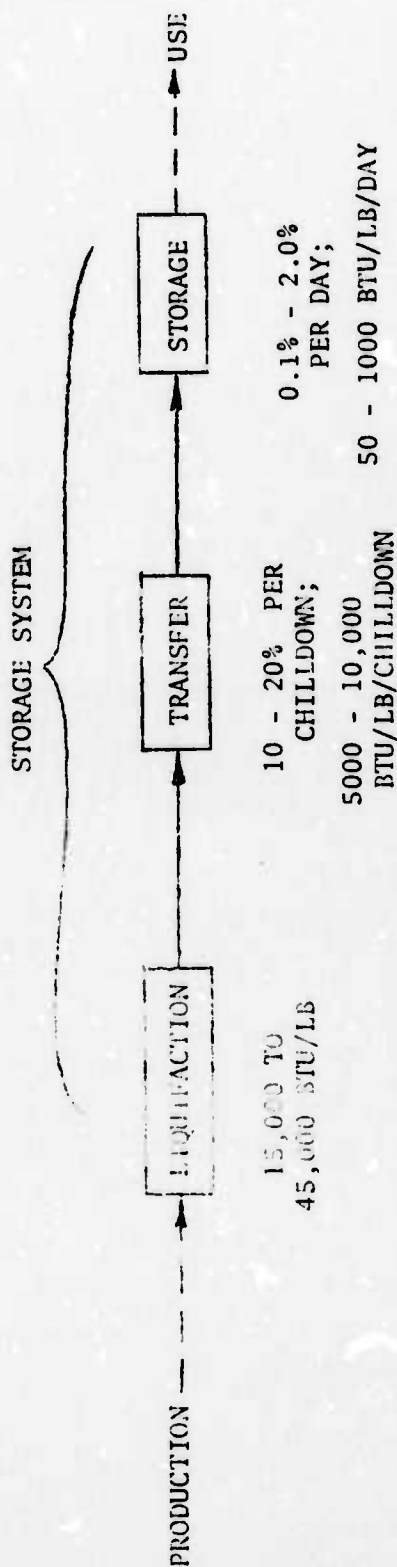


FIGURE 5
COMPARISON OF EQUIVALENCE RATIOS FOR HYDROCARBON
AND HYDROGEN GAS TURBINES (IDEAL BRAYTON CYCLE) AND
EQUAL TURBINE INLET TEMPERATURES



(CP., LOWER HEATING VALUE OF H_2 = 52,000 BTU/LB)

FIGURE 6

PRELIMINARY STORAGE-SYSTEM-LOSS DATA

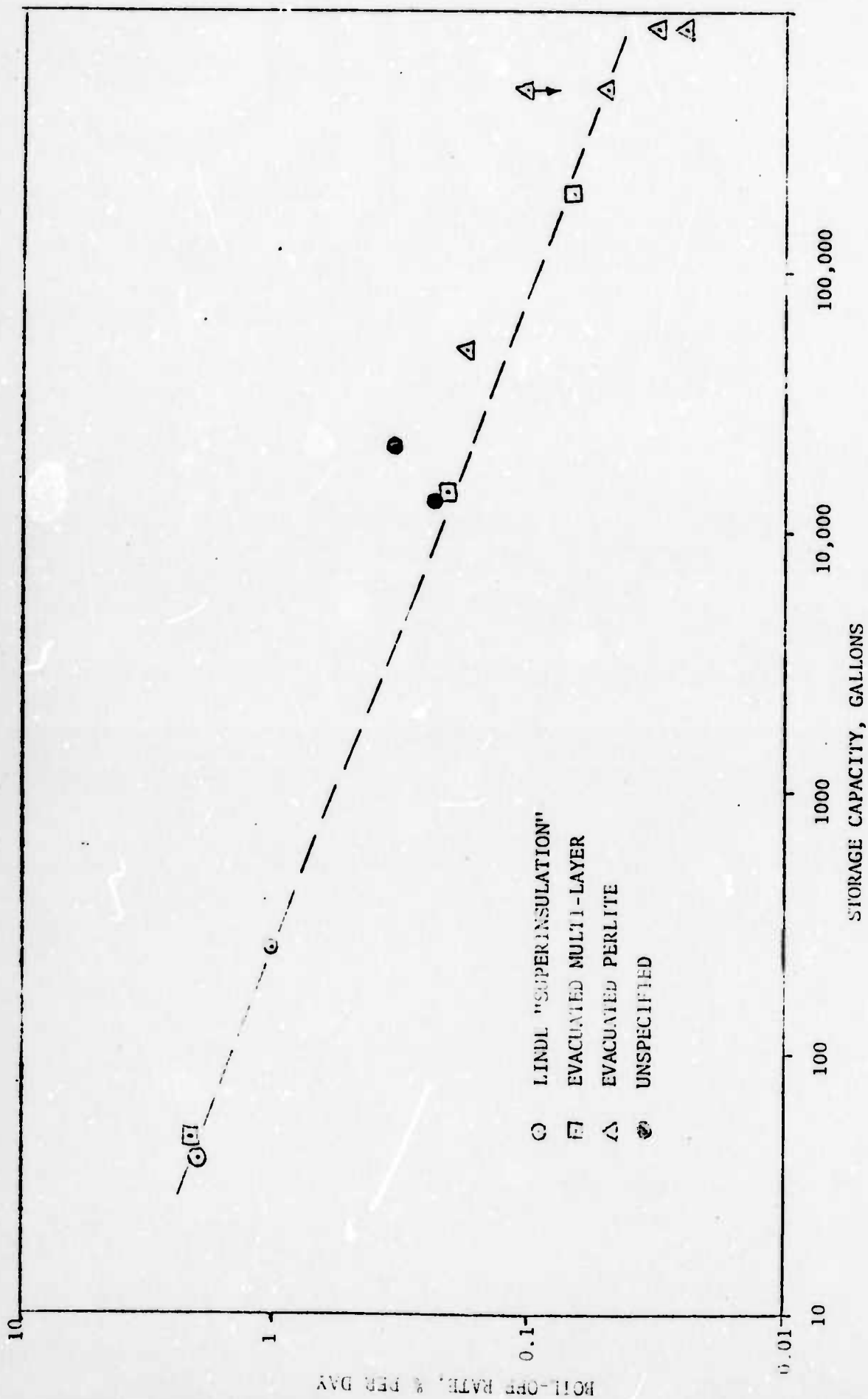


FIGURE 7
BOIL-OFF RATES OF CRYOGENIC HYDROGEN
IN VARIOUS SIZES OF TANKAGE

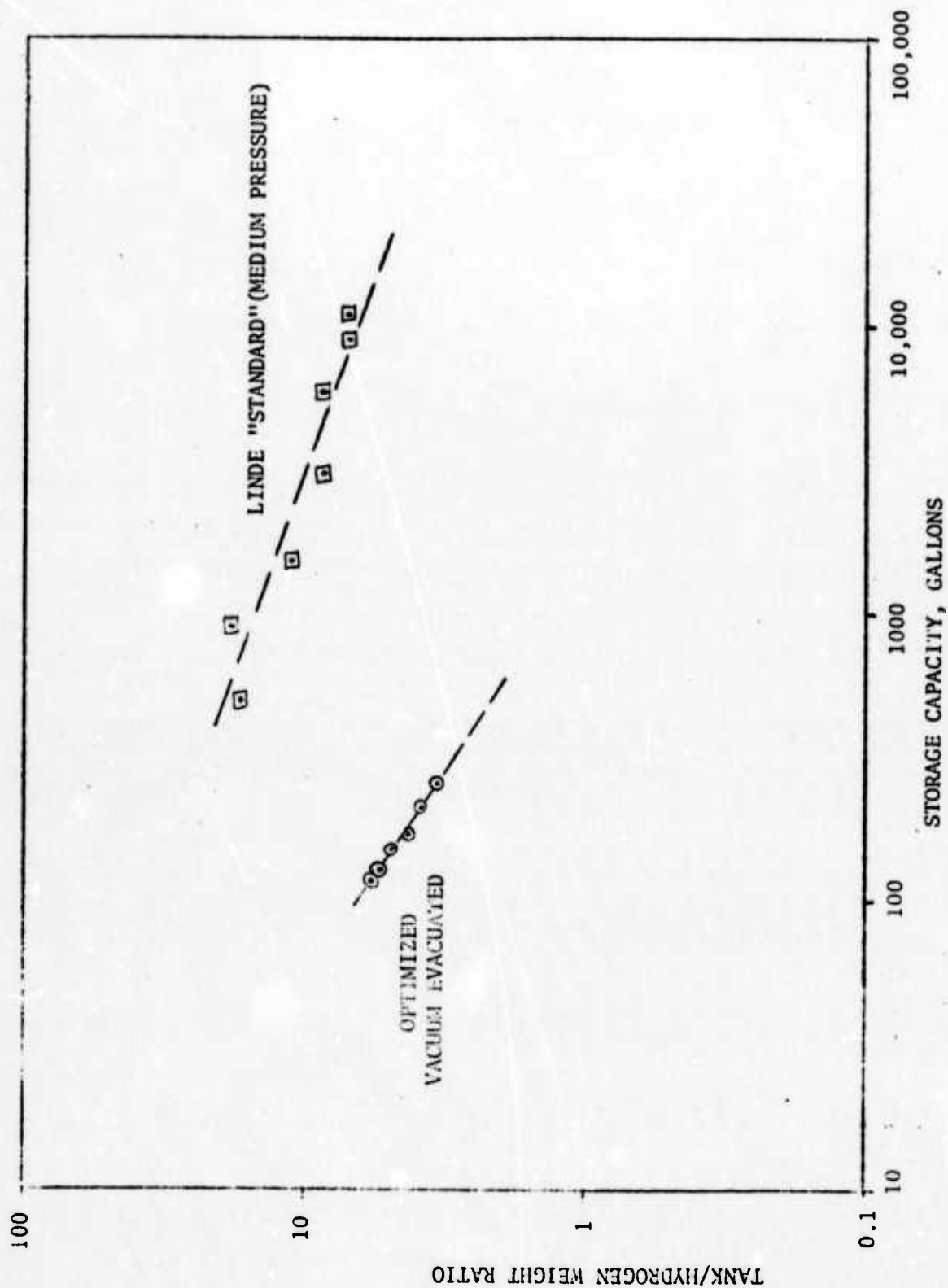


FIGURE 8

TANK/HYDROGEN WEIGHT RATIOS FOR VARIOUS SIZES OF TANKAGE